

Analysis of the DEBI flight data

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Abstract:

The investigation of hypervelocity shocks that began with the highly successful Bowshock I and II atmospheric sounding rocket experiments continued with the DEBI flight experiment. Instruments aboard the earlier vehicles performed measurements of the ultraviolet and vacuum ultraviolet emission excited in the high temperature gas produced by the shock ahead of the hypervelocity body. With the DEBI experiment, we developed the experimental techniques and the instruments necessary to expand those earlier experiments into the infrared portion of the spectrum where ground-state, molecular, ro-vibrational emission can be observed as the most direct measure of shock temperatures.

With the previous project's support, we defined, designed, constructed, and successfully flew the hypervelocity shockwave experiment that has come to be known as "DEBI". The flight instrumentation originally proposed made some evolutionary changes as a result of new thoughts on the spectral regions to emphasize, detector developments, and background suppression techniques that greatly improved the infrared measurements. The flight was a complete success, with the launch vehicle and all instruments working perfectly.

This project's goal was to perform the extensive analysis necessary on the huge data set acquired on the DEBI flight and in the months of preflight calibration and testing. Most unfortunately, only about one third of the approved budget for the analysis proposal was ever funded. Hence, work necessarily stopped in the preliminary stages of the analysis with little net result for the entire project. A great wealth of completely unique data is about to be lost.

Synopsis of the DEBI project:

Optical diagnostic instrumentation aboard high-speed, atmospheric, sounding rockets has proven to be a very successful way of investigating hyper-velocity shocks. The intensely heated air in the shock produces optical radiation from both atomic and molecular species over a wide spectrum. This radiation is characteristic of the shock conditions, and can be used to derive temperatures and species densities in the shock region. The Bowshock I and II experiments concentrated on the shorter wavelength regions of such emission, specifically the ultraviolet emission due mostly to nitric oxide and OH, and the vacuum ultraviolet emission due to atomic nitrogen, hydrogen and oxygen. Modeling of these emissions has proven to be a challenging task, and it is now clear that measurements in other portions of the spectrum would be important to validate the conclusions of these models. The number of data points is at present very small, and without such validation it is not yet clear what power of prediction exists for other, unmeasured conditions. These experiments were characterized by a close collaboration between the experimental and modeling teams, which was essential for the objective--better understanding of the shock characteristics including temperatures, densities, and species composition. The net result was a data set and modeling evolution that has proven its usefulness in improving our understanding of this phenomenon. In order to continue this valuable process, new measurements must be made in order to test the models as they exist at their present state of evolution, and to provide insights into how they might be improved.

Moving our observations into the infrared, we can observe emission from ground state molecules that are part of the ambient atmosphere, in addition to those that are created in the shock chemistry. This becomes a powerful test of the models' ability to predict the

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shock "temperatures". For example, if the vibrational temperature of nitric oxide created in the shock was first fit by ultraviolet observations of the Gamma bands, then that same temperature should apply to ground state ro-vibrational emission observed in the infrared from the nitric oxide fundamental band or its overtones. Similarly, the carbon dioxide fundamental or its overtones could be observed and vibrational temperatures compared with those of nitric oxide. Hydroxyl excited state emission observed in the ultraviolet also has ground state ro-vibrational bands in the infrared as a further check on this process.

We defined, designed, constructed, and flew a suitable set of instruments on a sounding rocket that nearly duplicated the altitude and velocity regime of the Bowshock I experiment. These instruments included ultraviolet photometers, infrared radiometers, and a scanning IR spectrometer. As on the previous Bowshock experiments, we viewed not only in the forward direction, directly at the stagnation point, but also at an angle to the velocity vector.

All the instruments also had their input from fiber optics running between their respective entrance apertures and the appropriate windows. For the UV measurements on BSI & II, quartz fibers worked well, but do not transmit far enough into the IR. Fortunately, there does exist a new fluoride glass fiber material with excellent transmission out to nearly 5 microns. Hence the location of the instruments can be separated from their viewing geometry requirements, without which it would have been impossible to fit even this instrument set into the very small payload package.

It was impossible to fit all the desirable instrumentation into any payload with such limited resources, or even to use conventional designs for them. We believe that the instrument suite described below presented a good compromise of measurement coverage and practicality for this flight.

Optical Instrumentation Overview:

UV filtered photometers – Two Channels

- One channel in each look direction
- $\sim 0.24\mu$ band center
- Photomultiplier detectors, pulse counting only

Micro Optic Multispectral Radiometer (MOMS) – Fourteen Channels

- Eight channels of MWIR (3—4.3 μ wavelength)
- Six channels of SWIR (1.0—2.7 μ wavelength)

Scanning IR Spectrometer (1.0 - 3.0 μ) – Sixteen Channels

- Dual Look Direction
- Eight Detector Channels in each look direction

Look Directions:

- One spectrometer input and one UV photometer looking forward at stagnation point through recessed window in nose piece
- Second spectrometer input, second UV photometer, and all IR MOMS channels observing sideways through two recessed windows located as far forward on nose piece as practical

Instrument Specifics:

Two UV filtered photometers

Inputs coupled to windows with UV silica fibers.

Side-looking fiber area 10x that of forward-looking fiber for maximum dynamic range in signal levels

~240nm band center, ~50nm filter bandpass (FWHM)

Photomultiplier detectors, CsTe cathode—very low noise and “solar blind”

Detector pulse counting outputs integrated with 20 bit counters

“Legacy” data for overlap with BSI & II

Fourteen IR MOMS Radiometers

Eight channels of MWIR (3--4.3 μ wavelength)

Six channels monitoring 3-4 μ region with 0.2 μ spacing, ~0.2 μ filter bandpass

One channel ~4.3 μ band center for CO₂, ~0.2 μ filter bandpass

One channel ~0.8 μ filter bandpass centered at ~3.5 μ for maximum sensitivity.

Six channels of SWIR (1.0—2.7 μ wavelength)

Provide: spectrometer backup (as on BSI & II), high temporal resolution, high sensitivity

Place filter bandcenters at emission peaks and predicted “holes”

(2.7 μ CO₂, NO; 2.3 μ “hole”; 2 μ CO₂; 1.5 μ OH; 1.27 μ O₂; 1.0 μ)

All photodiode detectors cooled (below -120C) before flight, with sufficient heat capacity to maintain temperature for the next 40 seconds

InGaAs, and HgCdTe photodiode detectors

Inputs coupled to windows with fibers:

Wavelengths <2.5 μ will use IR Silica

Wavelengths >2.5 μ will use IR Fluoride glass

Optics and filters 5mm diameter

Each detector output into individual gated integrator preamplifier, then digitized to 20 bits resolution

Scanning IR Spectrometer

Modified Fastie-Ebert optical design, 300mm focal length

Dual spectrometer input slits coupled to windows with IR Fluoride glass fibers

Fast scan, ~0.5 second

~1.0 - 3.0 μ wavelength coverage

~0.05 μ resolution

Cooled (< -100C), photodiode detector array

Eight elements in each of two detector arrays

Photodiode types matched to specific wavelength region covered for best signal to noise

InGaAs for shortest wavelength region

Extended InGaAs (types 1-3) for intermediate regions

Photovoltaic, shortwavelength (1-3 μ), HgCdTe for longest wavelength region

Fast (f/0.5) relay lens system at exit slit for minimum detector size

Each detector output into individual gated integrator preamplifier, then digitized to 20 bits resolution

Results:

The DEBI experiment was successfully flown on a NASA Terrier-Malemute two stage

sounding rocket from Wallops Island, Virginia in June of 2003. The vehicle performed perfectly, following predicted parameters. The challenges of pre-flight cryogenic cooling of the payload were met, and the temperature at launch was ideal. Nose tip and radiometer detector temperatures were below -150°C as desired in order to reduce thermal background, give a good zero reference at nose tip ejection, and reduce detector noise to a minimum.

Telemetry and tracking were good, and all instruments performed perfectly. An extensive data set was acquired, beginning with nose cone deployment at an altitude of 35 km and a speed of 3.3 km/sec, continuing until loss of signal on the downleg portion of the flight. The preliminary "quick-look" shows substantial differences from the predicted model results.

We concentrated our data reduction efforts on the earliest portion of the data set, but much more, higher altitude data is left unexamined. Each data channel was stripped from the telemetry data stream, laboratory calibrations were applied to all the detector channels, proper backgrounds were subtracted, spin modulation was removed, and a method was developed to minimize the effect of the finite scan time of the spectrometer in skewing the data with altitude due to the rapid change in the bowshock signal intensity.

A problem was uncovered in the stagnation point look direction data. Thermal contact between the nose tip and the rearward thermal mass was partially lost, causing a rapid rise in the nose tip temperature. We discovered that the nose tip radiation could be fit to a blackbody curve, and modeled with a sophisticated thermal analysis software package, thus allowing subtraction from the spectrometer signal in each channel and recovering that data.

Approximately one third of the originally proposed analysis work was completed, on schedule and in budget. Since only one third of the originally approved budget was actually funded, work was necessarily stopped at this point, with little net result for the DEBI project and its huge, unique data set.

It is very clear that a great deal of work needs to be done in this area in order to develop our understanding of the chemistry and physics of such hypersonic shocks, and to expand the experimental data available for study. This project could have contributed to that understanding.

REPORT DOCUMENTATION PAGEForm Approved
OMB NO. 0704-0188

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1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE 06/02/2005	3. REPORT TYPE AND DATES COVERED Final Report, 10/1/2003 – 2/28/2005
4. TITLE AND SUBTITLE Analysis of the DEBI Flight Data		5. FUNDING NUMBERS DAAD19-03-1-0348	
6. AUTHOR(S) Dr. Peter Erdman			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Embry-Riddle Aeronautical University 600 S. Clyde Morris Blvd. Daytona Beach, FL 32114-3900		8. PERFORMING ORGANIZATION REPORT NUMBER 61135	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U. S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211		10. SPONSORING / MONITORING AGENCY REPORT NUMBER 45790.1-EG	
11. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.			
12 a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.		12 b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The investigation of hypervelocity shocks that began with the highly successful Bowshock I and II atmospheric sounding rocket experiments continued with the DEBI flight experiment. Instruments aboard the earlier vehicles performed measurements of the ultraviolet and vacuum ultraviolet emission excited in the high temperature gas produced by the shock ahead of the hypervelocity body. With the DEBI experiment, we developed the experimental techniques and the instruments necessary to expand those earlier experiments into the infrared portion of the spectrum where ground-state, molecular, ro-vibrational emission can be observed as the most direct measure of shock temperatures.			
14. SUBJECT TERMS Hypervelocity Shocks, Bowshock, Atmospheric Sounding Rocket Experiments., Debi Flight Data		15. NUMBER OF PAGES 4	
		16. PRICE CODE	
17. SECURITY CLASSIFICATION OR REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION ON THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI Std. Z39-18
298-102